

Proceedings of the Right Light 4 Conference, November 19-21, 1997, Copenhagen, Denmark.

On the Calibration and Commissioning of Lighting Controls

Francis Rubinstein, Douglas Avery, Judith Jennings
Building Technologies Program
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California, USA, 94720

Steven Blanc
Pacific Gas & Electric Company
Customer Energy Management Dept., Research & Development Group
2303 Camino Ramon, Suite 100
San Ramon, California, USA, 94583

October 1997

This work was supported by the U.S. General Services Administration, Pacific Rim Region, the Pacific Gas & Electric Company, and the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Equipment of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

On the Calibration and Commissioning of Lighting Controls

Francis Rubinstein, Douglas Avery, Judith Jennings
Building Technologies Program, MS 90-3111
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, California, USA, 94720

Steven Blanc
Pacific Gas & Electric Co.
Customer Energy Management Dept., Research & Development Group
2303 Camino Ramon, Suite 100
San Ramon, California, USA, 94583

ABSTRACT

Lighting controls have the potential to capture significant energy savings in commercial buildings if properly specified, installed, commissioned and maintained. Proper commissioning is often absent in lighting projects and the lack of commissioning can significantly reduce a project's energy savings potential. The paper focuses on the importance of good commissioning practice for obtaining satisfactory performance from lighting control systems and discusses the difficulties of commissioning today's systems. Some practical suggestions for commissioning lighting controls is offered as well as advice to specifiers and early adopters to aid them in selecting controls that are most appropriate to their requirements.

INTRODUCTION

Lighting controls provide building operators with the means to manage the way lighting energy is used in buildings more efficiently. These systems use various control strategies to (1) reduce wasted hours of lighting in unoccupied spaces, (2) automatically adjust electric light levels in synchrony with available daylight or age-related changes in luminaire output or (3) selectively shed lighting loads to moderate peak demand (DOE 1993). Lighting control systems have been installed in a number of buildings worldwide but few of these installations have been adequately monitored to verify their energy performance. In the few available monitored studies, lighting controls have been shown to capture significant energy savings when the controls have been properly designed, specified, installed, commissioned and maintained. In some cases, these savings have been shown to persist for years (Rubinstein 1991). Yet these early projects have also tended to uncover various deficiencies in current equipment and practice that are likely to prevent today's controls from reducing lighting energy use sustainably in routine practice. Some of these flaws can be traced to inadequate commissioning and calibration of the lighting controls during or after installation to assure satisfactory system operation. Other issues relating to design, specification and installation are not treated in this paper. This paper discusses the importance of commissioning and calibrating today's lighting controls systems and presents some practical advice for effectively calibrating these systems.

A lighting control system typically consists of the following basic elements:

- *Dimmable ballasts* that are capable of responding to a control signal. (In the case of an occupant sensor, dimming ballasts are not required. A controllable relay that switches the ballasts would be used instead.)
- *A sensor that is capable of measuring or detecting a physical parameter of interest* (e.g., available daylight) and translating this into an electrical signal (e.g., a current or voltage).
- *A controller* that can accept the electrical signal from the sensor and convert this signal using a built-in algorithm into an electrical signal to the dimming ballast.

Sometimes, the above elements are combined in the same hardware. For example, the most common topology for daylight-linked lighting control in a private office in the U.S. is a low-voltage control loop for the electronic dimming ballasts connected to a two-wire photosensor. Here, the controller and dimmer are built into the dimming ballast circuitry itself and the only calibration adjustment is on the photosensor. To obtain satisfactory results, these components must be specified intelligently so that the different components work well together as a system. Specification is difficult, in the U.S. at least, because the components that comprise the final system are not usually produced by the same manufacturer and inter-operability of components from different manufacturers has always been problematic in the buildings industry.

Role of Commissioning and Calibration in Lighting Controls Projects

In the buildings industry, *commissioning* is defined as “a systematic process of ensuring that all building systems perform interactively according to documented design intent and the owner’s operational needs” (FPL 1997). The definition of commissioning is often broadened to extend through all phases of a project, from conception and design to occupancy and operation (BPA 1992). In a modern building project, which usually involves more than just the lighting system, commissioning is necessarily a team effort involving the commissioning agent, owner, designer, contractors, facility manager and the building operating staff. Ideally, the commissioning agent acts as an overseer throughout the design and construction process, and has overall responsibility for initially developing the commissioning plan in the pre-construction phase and then assuring that all required commissioning actually takes place upon installation. But it is the contractor (or subcontractor) who is responsible for installing the equipment properly and making all the necessary physical adjustments, calibrations, and tuning to ensure that the equipment functions according to the performance specifications detailed in the commissioning plan. After installation, the commissioning agent verifies that the contractor has performed all necessary commissioning by running specific tests that compare the system’s on-site operation to that detailed in the commissioning plan.

We have adopted a more limited definition of commissioning with respect to lighting controls, in which *commissioning* refers to all the activities that are required for the lighting control system to operate the lighting system according to design intent. It is important to stress that in many lighting projects, particularly lighting retrofits in existing commercial buildings, there may be no commissioning agent to fulfill the critical role outlined in the preceding paragraph. In fact, for the most common type of lighting retrofit (the replacement of T-12 fluorescent lamps and magnetic ballasts with

T-8 lamps and electronic ballasts) there may be little need for a separate commissioning agent since adequate commissioning for this simple retrofit merely requires verification of correct installation, a task that may be handled adequately by the general contractor. When a lighting control system is involved, however, its added complexity will not allow the lighting system to perform according to design intent without commissioning. Unfortunately, since commissioning as a distinct activity is not applied to many lighting projects, most lighting control systems are not commissioned at all.

The importance of commissioning to the success of a lighting control project can be seen by example. The California Energy Code, Title 24, requires that in new non-residential buildings, lighting zones not equipped with occupant sensors must be switched off (“swept off”) by computer after normal working hours. For the “sweep-off” system to reduce energy usage as intended by code, someone must ensure that the desired “off” times for each controlled zone in the newly-installed system have been entered into the computer program that controls the lighting system operation. Without this step, the lights may not be swept off automatically at all. The failure to commission the control system in this example could result in even greater energy use than a system with no controls at all.

In practice, the commissioning of most computer-based lighting controls is performed by adding or changing values in a manufacturer-supplied piece of software. As a rule, current software for lighting controls is woefully inadequate, difficult to use, and may be beyond the skills of the building personnel.

Calibration is that subset of commissioning activities that relates directly to the proper functioning of an electrical or mechanical sensor. It refers to an electrical or mechanical adjustment to a sensor to obtain the desired output from the sensor given the actual range of the input (a physical parameter such as light). Calibration is required for most sensors (whether they detect changing light levels from daylight or heat patterns from moving warm bodies) because it is not known *a priori* what range of inputs may be encountered by a sensor in any particular building application. An example of this is two adjacent daylit office spaces, one with dark, the other with light furnishings. Even if all the other physical conditions (such as the window size and orientation) are the same, one would expect light sensors in these two spaces to read significantly different values. The quantity of available daylight, in particular, striking the sensor is likely to exhibit extreme ranges, (from 0-100,000 lux) especially if the window treatment does not entirely exclude direct sunlight.

The actual calibration adjustment is usually accomplished by turning a set screw in a sensor (which may be relatively inaccessible) or on the controller. In more sophisticated systems, calibration may be accomplished via software. From a practical standpoint, it may be inconvenient or time-consuming to calibrate or commission the system, thus it may be mistakenly avoided altogether leaving the sensor to operate “out of the box” using factory default settings.

Because there are many ways to configure lighting control systems, the specific details of calibration and commissioning will vary from system to system. Furthermore, the distinction between commissioning and calibration as we have defined them can blur. But, generally speaking, the calibration and commissioning activities required for most modern lighting control systems are in the following table:

Table 1. Typical calibration and commissioning activities for different control types

<i>Control type</i>	<i>Calibration and commissioning activities</i>
Daylight-linked	Verify sensor placement and orientation for optimum operation. Adjust if required. Make adjustment at the light sensor or controller to obtain the desired light level at the work surface.
Lumen maintenance	Verify sensor placement for optimum operation. Adjust if required. Make adjustment at the light sensor or controller to obtain the desired light level at the work surface.
Occupant sensors	Verify placement and field of view for optimum operation. If unanticipated obstructions are present, adjust sensor location. Adjust the sensitivity and time delay of the occupant sensor.
Sweep-off	Input start/stop time and override processing.
Manual dimming	Set upper/lower limits of dimming range.

State of Current Commissioning Practice

Given that commissioning is required to obtain satisfactory operation from the lighting control system, the contractor should commission the system as soon as the controls hardware has been installed. But unlike in the HVAC industry, where the subcontractor who installs the ventilation system would also typically be responsible for commissioning the system operation, there are few electrical contractors that have any experience in commissioning lighting control systems. This lack of expertise is a serious barrier to the widespread adoption of lighting controls by the building industry. In order to overcome this hurdle with today's systems, it is necessary for contractors to develop the skills to properly commission the controls as part of installation and for this task to be included in the contract documents. The additional costs incurred by the contractor to commission the lighting controls must be included in the overall bid. To assist the contractors, manufacturers should make products that can be easily (quickly) commissioned and should include clear, step-by-step instructions for calibrating and commissioning their products, as components and as systems in a building application. Further manufacturer assistance, including being present on site when the contractor commissions the system and providing the contractor with any necessary specialized equipment (such as light meters) on a short term basis may be required to assure that the contractors perform the commissioning correctly. Until the electrical contracting trade gains the necessary experience to commission lighting controls systems, it is unlikely that lighting controls will sustainably reduce energy usage in routine practice.

Calibration of Daylight-Sensing Systems

Through the process of designing and running a large demonstration of several different lighting controls systems at the San Francisco Federal Building¹, the authors have gained considerable knowledge and practical experience in techniques for calibrating and commissioning currently available systems so that they function correctly. Of particular note is the logistical difficulty in calibrating certain types of daylight-responsive systems that use ceiling-mounted light sensors. The most appropriate location for the sensor in small spaces (such as private offices) is usually the ceiling near the primary work area. To calibrate this type of system, one must stand on a ladder adjusting a very small, hard-to-find, potentiometer (pot) in the sensor housing some 3 meters off the floor. Like Floyd (Floyd 1996), we found that the adjustment potentiometer on some sensors is overly sensitive in the range of interest, making precise setting of the light level difficult or even impossible. Because of the wide range of daylight and electric light levels possible in real buildings a sensor should include both a coarse and fine adjustment to allow efficient calibration regardless of light level. In our experience, this type of adjustment is not generally provided.

The difficulty of calibrating ceiling-mounted sensors is exacerbated by the fact that the individual performing the calibration must be close to the sensor, thereby blocking some of the light falling on it. This introduces considerable error into the calibration process. One way to overcome this problem is to provide a means to make the calibration adjustments at a distance from the sensor. A few currently available systems offer this capability, but to be physically possible, this approach requires the ceiling-mounted sensor to be wired to an accessible controller. Nonetheless, in our view the additional wiring is justified by the increased likelihood that the system will be calibrated correctly the first time.

Finally, it must be considered that correct calibration of a photo-responsive lighting system requires a photometer. This photometer (or light meter) need not be expensive (around \$200 U.S. dollars will purchase an adequate photometer for calibration purposes). If possible, it is advantageous to purchase a light meter with a long cable between the meter itself and the readout unit. This allows a long distance between where the light level is measured and where the calibration adjustment must be performed.

Calibration of Occupant Sensors

Calibrating an occupant sensor means setting the sensitivity and time delay for appropriate operation in the particular space where the unit is installed. Commissioning refers to verifying correct sensor location and orientation relative to the occupant location, room geometry and any obstructions. Occupant sensors are typically calibrated in two steps: by adjusting the sensitivity of the detector to movement within the space, and adjusting the time delay between the last detected motion and

¹ Lawrence Berkeley National Laboratory, in partnership with the U.S. General Services Administration and Pacific Gas & Electric Company, is currently conducting a series of studies designed to quantify the benefits obtained from the use of daylight-linked controls, occupancy sensors and other controls in a typical office building. This study, being conducted at the San Francisco Federal Building located at 450 Golden Gate Avenue, San Francisco, California, has been designed to measure actual savings realized from the use of lighting controls in different office applications. Individual offices, bullpen areas, and conference rooms are included in this study, with each space metered separately.

switching the lights off. For most sensors, these adjustments require that a cover plate on the sensor be removed so that the exposed knobs can be adjusted using a small screwdriver. To adjust the sensitivity, the installer first adjusts the time delay to its minimum value (usually around 15 seconds), then moves to each corner of the room to verify that he/she is detected in each location. Many sensors have indicator lights that will blink when motion is detected, which can speed the calibration. Next, sensitivity should be tested at the primary work station(s) in the area, by remaining still for a few minutes to ascertain whether or not the lights will extinguish. If they do, the level of sensitivity should be adjusted to ensure that the lights remain on while the room is occupied. However, if traffic passing by the open doorway of the space being controlled causes false tripping, the sensitivity must be reduced or the location or orientation of the sensor adjusted.

The length of the time delay or time-out should be based on the occupant's preference or the building operating procedure. In most occupant sensors the time delay can be set for as fast as 15 seconds, or as slow as 30 minutes. Factory default settings are typically 12 or 15 minutes. The amount of time that passes before the lamps are timed out will vary based on the habits of the occupants so each sensor in every controlled space should be individually adjusted.

There are a few factors that might influence how the time delay is set. If someone is in and out of their space for short periods frequently during the normal workday, a longer time delay would prove more efficient. This longer delay will cause fewer starts on the lamps (maintaining rated lamp life), and will be less of a potential nuisance for the occupant. If, on the other hand, the occupant tends to be in the space most of the time, and stays out of the space for longer periods of time, a shorter time-out would be appropriate.

The Significance of Commissioning

If a lighting control system is not calibrated and commissioned correctly, it is unlikely that the design intent—occupant satisfaction and significant energy savings—will be achieved. If a lighting system does not respond according to the occupant's expectations (for instance the electric lighting dims too much or too quickly as the sun moves out from behind a passing cloud), the occupant will be dissatisfied and may attempt to override the control system (for example, by taping over the light sensor perceived to be causing the unwanted changes in light level). Even if occupants do not try to circumvent the system, they can be expected to complain to building management. It is only human nature for the building personnel to respond by doing what they must to mollify the complainer regardless of the implications for energy efficiency. We know of instances where the building electrician has disconnected the sensor wires to eliminate occupant complaints.

Ironically, a defeated lighting control system usually ends in a state that causes maximum energy consumption. The opposite of the railway brakeman's "deadman's switch" (wherein the train came to a halt if the brakeman let go of the control lever), a disconnected sensor results in the lighting going to full power (full light output). In today's lighting control systems, it is best to fail with the lights on full for safety considerations. Thus as a consequence of the necessary control design philosophy, a failed or defeated control system will consume as much energy as a system not controlled at all. Clearly, the savings under these conditions would not justify the added cost of installing the lighting control equipment.

Equally important, if early adopters of controls are not satisfied with the way the systems operate because they were not commissioned properly, their experience will cause potential future users to avoid controls. As with many new technologies, it takes repeated positive results for the technology to be accepted, and one bad experience is likely to turn the user against controls technology for a very long time.

Solving the Problems Posed by Failure to Calibrate and Commission

Our work and the work of others has suggested that lighting controls are not properly commissioned as a rule. But this does not mean that we should abandon lighting controls. Rather, we need to educate early users and adopters of controls so that they include the cost of calibration and commissioning (as well as maintenance) in their cost evaluation for the project. A commissioning agent should be involved at the earliest point of the project to develop the commissioning plan. By formalizing the requirement for commissioning into the contract documents, there will be a new financial incentive to assure that the commissioning is undertaken. Electrical contractors need to acquire the skills required to calibrate and commission today's lighting controls. Building operators, also, must improve their skills so that the periodic calibrations required by any control system can be done.

Finally, we think this presents a challenge to controls manufacturers to develop and produce new systems and components that are sufficiently "intelligent" that the need to commission is eliminated or at least minimized. One example of this new technological approach is the occupant sensor from one U.S. company that boasts the ability to "learn" about its environment over a period of weeks. This device adjusts its sensitivity to motion and the time delays based on an heuristic algorithm. This system will, for example, increase its sensitivity to motion if it detects periods of increased occupancy. To our knowledge, intelligence has yet to be incorporated into any existing photo-responsive system. Embedded intelligence might allow tomorrow's controls to adjust to changing environmental conditions in such a way that calibration and commissioning becomes unnecessary.

Practical Suggestions on Calibration

In our experience, most commercially available occupant sensors, if properly installed, can be correctly calibrated and commissioned in about 5 minutes per sensor. Daylight-linked controls, on the other hand, require considerably more time to commission. Our results at the Federal Building have been mixed. The open-loop control system we tested at the San Francisco Federal Building (which has worked quite successfully for over a year with significant energy savings and no occupant complaints) could be calibrated in about 30 minutes by a skilled individual with the necessary equipment (i.e., light meter). Since these zones were fairly large (50 sq. meters), the cost of calibration per square meter would not be so high as to make the job uneconomical. In a private office, though, a 30 minute calibration time is too long for daylight-linked controls to be cost-effective at today's controls and energy costs.

The closed-loop, high gain, control systems we tested have not performed as well. In small daylight offices, these systems proved time-consuming to commission and even after careful adjustment, consistency of illumination levels was difficult to maintain from office to office.

Getting Better Performance from Lighting Controls

Lighting controls are relatively new to the buildings industry and the institutional mechanisms to ensure that lighting controls save energy effectively are not in place. But early adopters, if aware of these institutional shortcomings and prepared to take steps to overcome them locally, can make today's lighting controls systems more successful:

- Hire a commissioning agent during the design phase to develop a commissioning plan that includes all the lighting control systems in the scope. This plan should describe all aspects of the commissioning process including schedules, responsibilities, documentation requirements and functional performance test specifications.
- Select a contractor that can assist the commissioning agent in developing the commissioning plan and has demonstrated expertise in performing the functional tests required in the plan. Make commissioning a task in the work order and ensure that the contractor has competent personnel available to perform the commissioning at the right point in the construction schedule. Include the cost for calibrating and commissioning the control system in the job estimate.
- Specify controls that provide the necessary accessible calibration adjustments.
- Make sure that the maintenance and engineering staff of the facility are familiar with the installed technology and are able to maintain and periodically calibrate the system. Maintain a light meter.
- If periodic calibration is not to be done in-house, assure that calibration and periodic maintenance is written into the building maintenance contract.
- Take full advantage of the support offered by controls manufacturers.

In addition to our suggestions to specifiers and contractors, we also have advice to manufacturers of controls systems.

- Support the development and adoption of industry-wide standards for the performance of all lighting control components and systems. These standards should contain all the photometric and electrical characterization required so that components from different manufacturers can be intelligently specified to form functional systems.
- Make sensors easy to calibrate and factory preset systems so that adequate (if suboptimal) performance is achieved even if the device is not commissioned at all.
- Provide an easy-to-use graphical interface for all software that is required to operate the controls successfully. Wherever possible, provide sensible default values for the software and/or provide a means (such as set-up “wizards”) for extracting the necessary building operation data from the operator.

- Provide clearly written instructions for the installation of the controls hardware which takes into account the myriad of application conditions in which controls might be installed.
- Provide clear, step-by-step instructions to the contractor for the proper commissioning and calibration of the controls. Use an abundance of effective graphics.

Although this paper has been concerned primarily with commissioning and not with specification, a concluding comment about a commonly misspecified daylight-linked control system is appropriate. Most daylight-sensing systems in the U.S. use a particular high gain control algorithm (integral reset control). In common building applications in which daylight comes through a side window and the electric lighting is mainly direct, the use of this high gain control algorithm cannot be recommended because of the susceptibility of this system configuration to “illuminance sag”; a phenomenon in which total light levels at the workplane drop below design levels as more daylight enters the space (Rubinstein 1989). Although this problem can be mitigated in the field somewhat by intentionally setting the set-point too high, it is a suboptimal solution at the best of times. For most typical daylighting applications, a high gain control system should not be specified. Rather, the specified control system should have variable gain and allow adjustment of system sensitivity as well as set-point. That is, one should be capable to adjust how much the electric lights dim in response to a given increase in available daylight. The specifier is well advised to select a system configuration in which this critical control adjustment is available.

Conclusions

Today’s lighting controls have the potential to save significant amounts of otherwise wasted lighting energy in commercial buildings. Given the vast size of the commercial building stock and the prevalence of waste, this is a worthy endeavor. Yet automatic control systems must be calibrated and commissioned to achieve significant savings and fulfill their promise. The expertise to accomplish these critical activities has not been institutionalized into the building construction process. In some cases, experienced personnel can calibrate and commission today’s controls so that they remain a cost-effective addition to the lighting system. But widespread adoption of energy-savings lighting controls is unlikely to occur until more intelligent and/or more accessible systems become available.

References

- Bonneville Power Administration. 1992. “Building Commissioning Guidelines, Second Edition”. Prepared by Portland Energy Conservation, Inc.
- Department of Energy, Electric Power Research Institute and California Energy Commission. 1993. “Advanced Lighting Guidelines”.
- Florida Power & Light. 1997. “Commissioning for Better Buildings”. Prepared by Portland Energy Conservation, Inc.
- Floyd, D. and Parker, D. 1995. “Field Commissioning of a Daylight-Dimming Lighting System,” *Proceedings of the 3rd European Conference on Energy-Efficient Lighting*, Newcastle Upon Tyne, United Kingdom.

Reed, J., Pinkowski, C., Mapp, J., White, S., Hall, N., and Caldwell, B. 1995. "Lessons From a Daylighting Retrofit: A Case Study of a Building."

Rubinstein, F. 1991. "Automatic Lighting Controls Demonstration: Long-Term Results." Lawrence Berkeley Laboratory Report LBL-28793.

Rubinstein, F., Ward, G., Verderber, R. 1989. "Improving the Performance of Photo-Electrically Controlled Lighting Systems," *Journal of the Illuminating Engineering Society of North America*, vol. 18, No. 1, pp. 70-94.

Acknowledgment

This work was supported by the General Services Administration, Pacific Rim Region; the Pacific, Gas & Electric Co.; and the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Federal Energy Management Programs and by the Office of Building Technology, State and Community Programs, Office of Building Equipment of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. Each of the aforementioned project sponsors has contributed considerable support to the goal of improving energy efficiency in Federal properties. We particularly acknowledge the support of GSA's Peter Gaddy, Terry Pierce and Warren Sitterley whose cooperation and support made this project possible.